

ORIGIN OF THE RED EARTH AND GRAVEL DEPOSITS IN NANKOU PIEDMONT, NORTHWESTERN BEIJING, CHINA

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ABSTRACT

Analytic results of the mechanical and chemical composition, clay minerals, sedimentary structures and microtextures of the red earth and gravel deposits in Nankou piedmont, northwestern Beijing, China, suggest that the deposits have nothing to do with glaciation but are palaeodebris-flow deposits. During the period of their deposition, the climate was humid and hot with plentiful rainfall, and oxidation, physical and chemical weathering were rather intense. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: red earth and gravel deposits; analysis of mechanical and chemical composition; palaeodebris flow; Nankou piedmont; northwestern Beijing, China

INTRODUCTION

Nankou is located in the northwestern part of Beijing. A red earth and gravel layer is well developed in Nankou piedmont fluvial platform, and is distributed in a long extended shape with thickness of 1.5–2.0 (Figure 1). The top of this red earth and gravel layer in some places is covered by late Quaternary loess and its underlying sediment is a light laterite bed (Figure. 2). The origin of the red earth and gravel layer was considered as glacial debris (Wang and Pan, 1956; Wei *et al.*, 1982). We consider through detailed research into the mechanical and chemical composition and structures of the layer that the deposits have nothing to do with glaciation but are palaeodebris-flow deposits.

THE ATTITUDE AND LITHOLOGY OF THE GRAVELS IN THE RED EARTH AND GRAVEL LAYER

Five ideal outcrops (No. 1 to No. 5) and one hundred gravels on each outcrop were chosen on sections of the red earth and gravel layer for measuring and statistical analysis of the attitude, lithology and psephicity of gravels. The dip directions of the maximum flat planes (axial plane AB) of the gravels from No. 1 to No. 4 outcrops mainly concentrate between 300° and 350° but there is dispersion of the gravel dip directions from No. 5 outcrop. The facts show that the arrangement of the gravels in the red earth and gravel layer has the fabric pattern of gravels formed by stream flow; in other words, the maximum flat planes of gravels dip towards the upper reach of river flow. This characteristic fits well with gravels deposited by modern debris flows (Li, 1996). Therefore, the sediments may be inferred to flow and be deposited from northwest to southeast. The dispersed distributions of gravels on No. 5 outcrop are due to the No. 5 site being located at the end of the debris flow; at the front of the debris flow there is no lateral compression which made some gravels dip towards the frontal direction, and the dip directions are dispersed. This phenomenon is also found in the frontal keel of Jiangjiagou debris flow in Dongchuan of Yunnan Province. The gravels fell down and dip in various directions. Thus, we inferred that the red earth and gravel layer was a palaeodebris-flow deposit based

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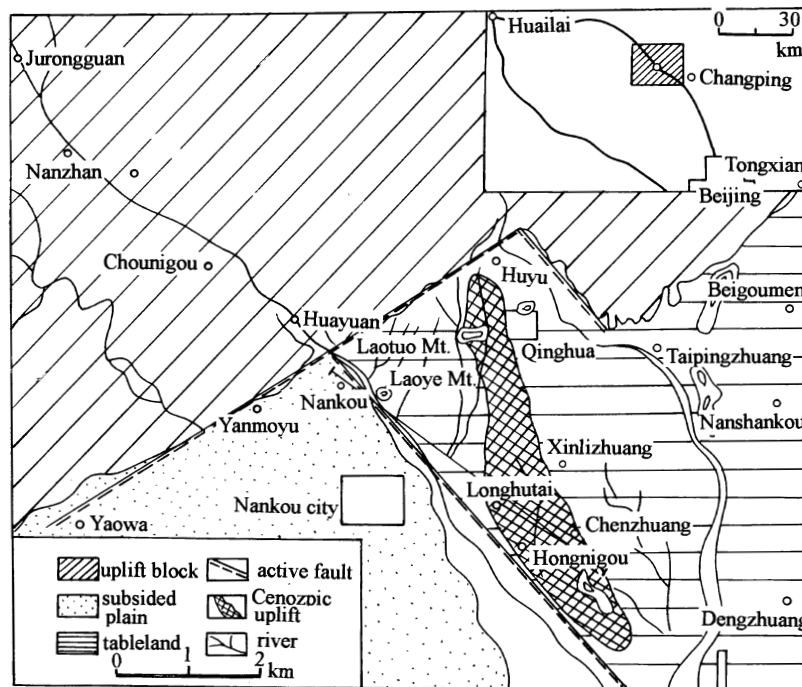


Figure 1. Tectonic landforms of the Nankou area

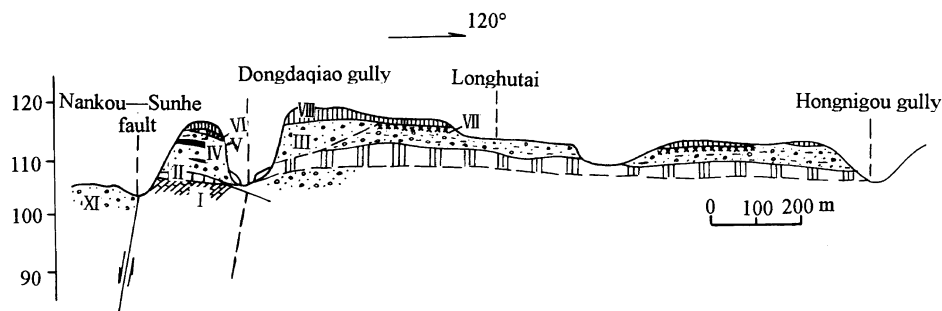


Figure 2. Geological cross-section between the Nankou river and Hongnigou gully. I, Sinian siliceous limestone; II, Pliocene dark red clay breccia; III, lower Pleistocene greyish white cement gravel bed; IV, lower Pleistocene light laterite; V, middle Pleistocene red earth; VI, late Pleistocene greyish white loose gravel bed; VII, Quaternary brown fossil soil; VIII, late Pleistocene secondary loess; IX, modern alluvial gravel bed

on the gravel dip characteristics and their distributing scope, and the frontal keel is located near Qijianfang reservoir.

The gravel lithology of the sediments is complicated according to field statistics and the lithological content is listed in Table I.

The lithology of gravels shows no difference from the bedrock in Nankou Mountain. The outcropping stratigraphy is from the Sinian System; most is siliceous limestone, siliceous dolomite and quartzose sandstone in Gaoyuzhuang Group and siliceous limestone in Dahongyu Group. The content of siliceous

Table I. Lithological component percentage of gravels from the paleo-debris flow in Nankou region

Lithology	Percentage	Lithology	Percentage	Lithology	Percentage
Siliceous limestone	55%	Quartzite	5%	diabase-porphyrity	1%
Siliceous dolomite	9%	Lamprophyre	4%	Felsite	2%
Quartzose sandstone	3%	Gabbro	2%	Aplite	3%
Sandstone	2%	Chert	3%	Aplite porphyry	2%
Argillaceous limestone	1%	Quartz porphyry	2%	Gneiss	2%
Granite	2%	Diabase	2%		

limestone of the Sinian System in gravels, however, is 55 per cent, and that of gneiss gravels is only 2 per cent, with little content of weathering granite gravels. Thus, we can infer that the palaeodebris flow originated in the Nankou Mountain, but the sourcehead was not far from the front because a large amount of gneiss outcrops around Chounigou which is about 2 km from the mountain front. The palaeodebris flow might have been formed along a small, steep palaeogully and caused by rainstorm with weathering fragments.

The psephicities of gravels in the palaeodebris-flow sediments are very different. Some are very good, up to grade 4, the lithologies of these gravels being mainly magmatic rock and dyke rock. The other gravels are hardly rounded, fragments weathered from bedrock being of psephictic grade 0 or grade 1; the lithology of most of the unrounded gravels is siliceous limestone. The mixture of psephictic and unrounded gravels shows that the palaeodebris-flow gravels are mainly from weathering crust on slope and from stream bed or terrace gravels.

We consider from this analysis that the palaeodebris flow originated from a gully of Nankou Mountain, flowed to the mountain front and towards the southeast to Qijianfang reservoir. The sediments distributed as a long extended shape about 4 km in length.

STRUCTURAL CHARACTERISTICS OF THE RED EARTH AND GRAVEL DEPOSITS

The structural characteristics of the percentages of gravel distributing areas (Ds%), volume (Dv%) and weight (Dg%) from measurements and statistics in different sites and horizons are as follows.

1. The values of Ds%, Dv% and Dg% in the lower horizon are higher than in the upper horizon in different measuring sections (Table II). The reason is that gravels mixed with slurry move forwards and are deposited under the action of gravel dead weight during transport; the further gravels are transported, the more gravels are deposited in the lower layer and fewer in the upper layer. In addition, current water gradually reduces during the late stage of debris deposition and transport capacity reduces causing large gravels to be deposited. This is termed a graded bedding sequence (Cui, 1986). The average grain diameter in the upper layer is 12.27 cm which is smaller than that of gravels in the lower layer (about 24.3 cm average particle size).
2. Some large gravels of siliceous limestone with strong weathering with diameters up to 30 cm existed in the upper layer, and many small gravels of siliceous limestone with weak weathering with diameters of only 15 cm were deposited in the lower layer. The reason is that the specific weight of gravels with strong weathering is smaller than that of weak weathering gravels. Also, the mud mixture has large buoyancy to support light large gravels.
3. The gravel content is larger with increasing transport distance along the longitudinal section, but gravel content is relatively reduced when mud and rock flow to a given distance (Figures 3 and 4). This can be explained because slope is steep at the beginning of transport to make flow velocity fast, kinetic energy large and transport capacity strong, so gravels in mud are mainly moved to the downstream reach. The gravels buoyed on mud are gradually deposited as their capacity is exhausted, kinetic energy consumed and transport capacity becomes smaller, therefore gravel deposit contents increased as transport distance

Table II. Values of area percentage (Ds%), volume percentage (Dv%) and weight percentage (Dg%) in the upper and lower layers in the sections at locations No. 1 to No. 5

Site	Horizon	Ds%	Dv%	Dg%	Amount that lower layer exceeds upper layer		
					Ds%	Dv%	Dg%
No. 1	Upper	8	11	15	17.5	9	15
	Lower	25.5	20	30			
No. 2	Upper	12	16	24	18	8.8	14
	Lower	30	24.8	38			
No. 3	Upper	14	17	29	16	9.4	15.3
	Lower	30	26.4	44.3			
No. 4	Upper	15.4	24.8	42	24.6	9.2	10
	Lower	45	34	52			
No. 5	Upper	13	20	32.3	12.6	10	9.7
	Lower	25.6	30	42			

increased. But Ds%, Dv% and Dg% values are reduced at No. 5 site, the end of the debris flow, because of the small gravel content there (Table II).

- Gravels with similar size and shape were deposited at different depths because of their different weight at each measuring site. The gravels with large specific weight such as magma and basic vein rock were deposited in the lower part. But gravels with the same lithology, size and shape were deposited at different depths because of their different weathering degree: the deposit location of weak weathering gravels is much deeper than that of strong weathering gravels. This is obviously controlled by gravel density.

The deposit characteristics only occur in the transport medium of water or water and mud mixture, especially in mud and rock flow to form graded bed sequences. These features could not occur in a glacial deposit because the transport forms of gravels are rolling and gliding (Cui, 1981, Li *et al.*, 1981).

MICROSTRUCTURAL CHARACTERISTICS OF THE RED EARTH AND GRAVEL DEPOSITS

The microstructural features of the red earth and gravel deposits were studied by electroscan microscope and are similar to those of modern debris flows.

- Irregular triangular pore spaces are well developed among fine grains in section. The pore spaces might have been formed by depositing pressure, epigenesis of moisture loss and gas bleeding. The phenomena are usually seen in modern debris-flow deposits.
- Compressional foliated structures and fine grains flowing around clasts are developed in horizontal planes which are similar to those of modern debris-flow deposits. These may be formed by laminar flow and epigenesis of dead weight caused by moisture loss.
- En echelon* tensional fractures dip towards the flow direction along the longitudinal section. These are caused by different flow velocities in the lower, middle and upper parts which can produce relative horizontal shearing to form tensional fractures with this orientational arrangement. The sediment flow direction inferred by the tensional fractures coincides with that determined by the analysis of sediment distribution and maximum flat planes of gravels.
- The quartzose sands with diameters of 0.3–0.5 mm observed by scanning electron microscope are well rounded with intense dissolution on the grain surfaces, which shows that the quartzose sands were eroded by water.

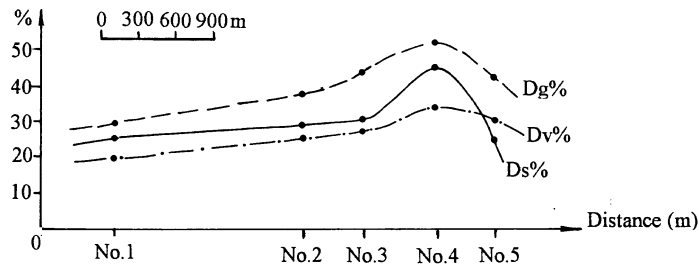


Figure 3. Diagram showing the variation of Ds%, Dv% and Dg% in the lower layer of palaeodebris flow with distance L in Nankou region

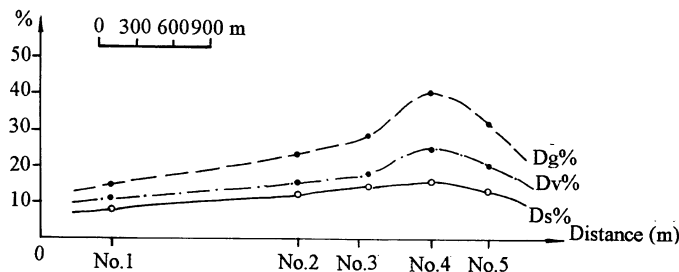


Figure 4. Diagram showing the variation of Ds%, Dv% and Dg% in the upper layer of palaeodebris flow with distance L in Nankou region

THE CLAY MINERALS AND CHEMICAL COMPOSITION OF THE RED EARTH AND GRAVEL DEPOSITS

Features of placer minerals (specific weight > 2.9, particle diameter < 0.3 mm)

The overall characteristics of placer minerals are low content, small size and uniformity of type. They are mainly iron oxide and hydroxide such as limonite, ilmenite, hematite and magnetite which constitute 70–80 per cent of all placer minerals. The crystal forms are well preserved; most of them are hypidiomorphic crystals with slightly rounded edge angles. The transparent minerals are mainly epidote and tremolite, the content of which is about 10 per cent. The crystal forms are allotriomorphic crystals and irregular fine granular, which show that the red earth and gravels have not been transported far from the site of origin.

Most of the placer minerals are extremely stable and have high resistance to weathering, but there is a lower percentage of unstable minerals such as hornblende and biotite in the placer minerals and also a low content of relatively stable minerals such as epidote and tremolite from the placer mineral distribution of the sediments (Table III). The facts indicate that most materials of the red earth and gravels were from weathering crust which experienced intensely physical and chemical weathering to form unstable minerals which decomposed and broke down, and resistant weathering minerals which remained in situ.

Features of clay minerals

Selected clay particles of diameter < 2 μm from the non-organic and decalcified samples were studied by X-ray diffraction analysis, differential thermal analysis, infrared spectroscopic analysis and electron microscope analysis. The results were as follows.

Table III. Heavy mineral distribution in the palaeodebris-flow deposits and in weathering crust in Nankou region

Site	Heavy minerals*			
	Extremely stable minerals	Stable minerals	Relatively stable minerals	Unstable minerals
No. 30 Hongnigou Upper layer	Limonite Zircon Tourmaline Rutile cassiterite	Magnetite Hematite Ilmenite Sphene	Epidote Diopside Tremolite	Hornblende Biotite
No. 28 Hongnigou Lower layer	Limonite Zircon Rutile Spinel	Magnetite Ilmenite	Epidote Tremolite	Hornblende
No. 31 Laoyeling Lateritic crust	Limonite Zircon Tourmaline Rutile Spinel	Magnetite Ilmenite	Epidote tremolite	

* Specific weight > 2.9; particle diameter < 0.3

1. The clay minerals are mainly vermiculite, illite and kaolinite, and also a little hydrokaolinite. Illite and kaolinite decrease from upper to lower layers, but vermiculite increases. The diffracted peaks of vermiculite (14×10^{-10} m), illite (10×10^{-10} m) and kaolinite (7×10^{-10} m) are very distinct from X-ray diffraction analytic spectra (Figure 5).
2. Illite shapes observed under electron microscope are fine sheets with rounded boundaries which are ideal shapes of illite in detrital sediment and weathering crust. There is a little kaolinite with imperfect crystals; the shape of hydrokaolinite is tubular, with irregular fractures in the end of the pipe caused by dehydration.
3. The clay minerals in the red earth and gravel deposits and weathering crust are similar in type and assemblage features.

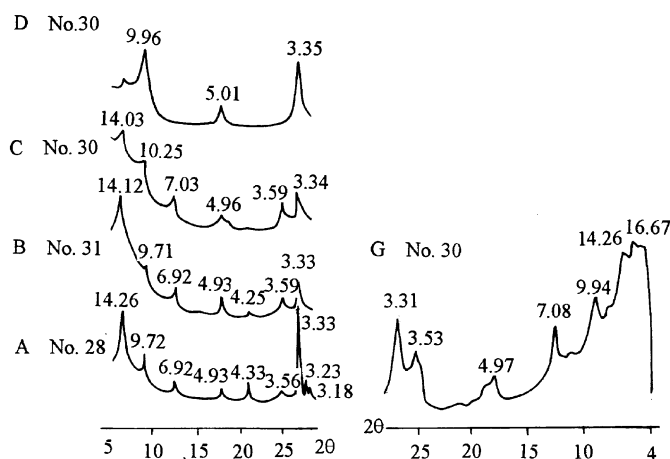


Figure 5. X-ray diffraction spectra of clay minerals. (A, B, C) Unprocessed samples; (D) thermally treated (600°C) samples; (G) samples treated by using ethylene glycol. Illite, 10 Å, 4.9 Å, 3.3 Å; vermiculite, 14 Å, 3.5 Å (10 Å after thermal treatment at 600°C); kaolinite, 7 Å, 3.5 Å; montmorillonite (mixed layers), 16.7 Å

Table IV. Mineral component and chemical composition of clay in the deposits of palaeodebris flow in Hongnigou gully section

Site no.	Layer*	Clay minerals†				Chemical composition (%)												
						SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	NaO	K ₂ O ₃	TiO ₂	P ₂ O ₅	SiO ₃ /Al ₂ O ₃	SiO ₂ /R ₂ O ₃	Fe ²⁺ /Fe ³⁺
30	U	K ≈ I V V	K L	I L	V S	41.48	23.49	8.90	1.38	2.12	1.17	0.19	2.20	0.72	0.20	3.00	2.42	5.82
31	M	I ≈ K V V				42.56	23.22	10.19	0.77	3.35	0.11	1.50	2.68	0.81	0.16	3.12	2.43	11.88
28	B	I V K	↓ S	↓ S	↓ L	44.04	23.22	9.44	0.18	2.57	0.99	0.30	2.50	0.78	0.11	3.22	2.56	47.21

* U, upper; M, middle; B, bottom

† K, kaolinite; I, illite; V, vermiculite; L, large; S, small

Characteristics of chemical composition

The Hongnigou section is taken as an example. The clay minerals and chemical composition are listed in Table IV. The SiO₂ content increases slightly from the upper to the lower part on the section; SiO₂/R₂O₃ and SiO₂/Al₂O₃ also increase but the ranges are smaller. The content of ferric iron is consistent from the upper to the lower part, but the Fe²⁺ content changes a lot: the content in the upper layer is 7.7 times that in the lower layer, and Fe³⁺/Fe²⁺ ratio is larger than 1, about eight times in the lower part than in the upper part, which shows that the lower layer was under more oxidation than higher the upper layer. The content of Al₂O₃ and Fe₂O₃, however, is also higher giving the clay a red colour (i.e. laterization) and forming a red weathering crust. The red clay and residual rubble provided a large amount of materials for late debris flow, and glacial debris and glaciofluvial deposits may not have so much red clay material.

THE MECHANICAL COMPOSITION OF THE RED EARTH AND GRAVEL DEPOSITS

Granulometric analysis is extensively applied to studying the depositional environment because granularity is the most important structural feature of detrital sediment. Therefore, granulometric analysis is an effective method to diagnose sediment type and reconstruct the palaeoenvironment.

The granular frequency curve of glacial sediments in the Tibet region shows that the peak value is always 4–5 ϕ in granular range (Shi *et al.*, 1985). The granular range of 4–5 ϕ reflects the glaciation environment of mechanical abrasion. The frequency curve of granulometric analysis of the red earth and gravel deposits in the Nankou piedmont shows that the granular range is 4–7 ϕ (Figure 6). The facts indicate that the red earth and gravel deposits did not experience mechanical abrasion of glaciation; these are features of the frequency curve of debris-flow deposits.

CONCLUSIONS

The analytic results of the red earth and gravel deposits in Nankou piedmont from the methods described and comparison with modern debris-flow deposits and glaciofluvial deposits show:

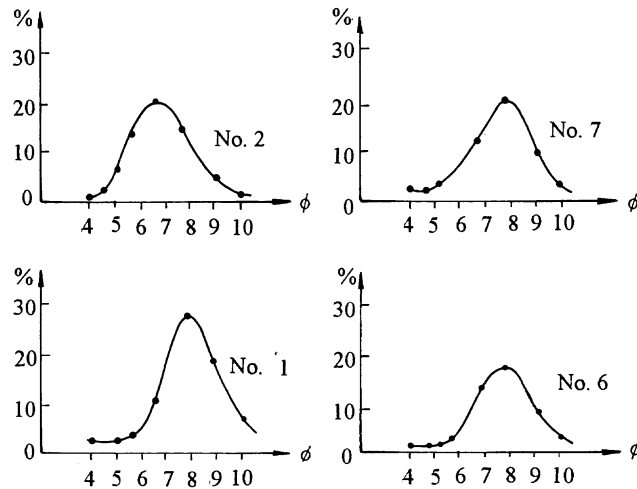


Figure 6. Curve of grain-size distribution of the piedmont red earth and gravel layer in the Nankou area

1. the red earth and gravel deposits are palaeodebris-flow sediments, with no glaciation;
2. the palaeoenvironment during the formation of the red earth and gravel deposits in Nankou piedmont had a humid and hot climate, with plentiful precipitation and intense physical and chemical weathering.

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